Attachment 18

THE POTENTIAL IMPACT OF A FLOATING TIRE BREAKWATER ON AREA WATER QUALITY AND FISHERY RESOURCES IN PRESQUE ISLE BAY

FINAL REPORT - July 1983

By

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ABSTRACT

The results of an environmental and fisheries resource study on the potential impact of installing a Floating Tire Breakwater (FTB) in an area of Presque Isle Bay, Erie, Pennsylvania are presented. Overall, from a review of the chemical, physical and biological data obtained, it can be concluded that the FTB caused little or no long term changes in the water characteristics and quality in the FTB site area; this statement is made by comparing baseline data (measurements made away from the FTB site) with data obtained at the FTB installation. From qualitative observations on the fish activity in the FTB area during the summer of 1982 (no FTB in place) and in the spring and summer of 1983, it appears that fishing activity has increased at the FTB site due to its presence. The FTB is providing significant wave protection to the boaters using the municipal launching ramp located in the area.

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1.0 INTRODUCTION

Floating Tire Breakwaters (FTB's) are rapidly becoming common structures that punctuate the coastlines of our oceans, bays, lakes and rivers. This proliferation in FTB's stems from the need to protect our coastlines and harbors from water wave destruction with low cost, effective, wave attenuating coastal structures. Floating tire breakwaters are apparently filling this need. The concept of floating breakwaters has been known for many years and were functionally prominent in the Allied Normandy invasion in World War II, 1944.[1] However, in recent years, the use of floating breakwaters gained impetus due to research at the Goodyear Tire and Rubber Company, Akron, Ohio by Mr. Richard D. Candle.[2] During his investigations on potential uses for scrap automobile tires, an idea for a simple configuration of tires bundled together in a continuous matt-like array was conceived and reduced to practice as an effective floating breakwater structure. Studies on FTB designs, harbor protection devices, and fishing reefs were also carried out by Candle. During this period, research to confirm and expand upon the Goodyear studies were subsequently carried out by Niel Ross[3] and also T. Kowalski[4] at the University of Rhode Island.

More recently, engineering measurements on FTB's have been carried out on the Goodyear design by Sorenson, Giles, Pierce and Lewis[5,6] and by Harms[7] on another FTB design. For a complete review of the structural details of present FTB installations, the reader is referred to the reports by DeYoung[8] and Bishop[9].

Concurrent with this activity of using assemblies of floating scrap tires to attenuate water wave action came the observation that bundles of scrap tires could possibly be used as a fishing reef. The reason for this is that during the early work on FTB's, increased fish activity was noticed in the vicinity of installed FTB's. Fish seemed to be attracted to such structures. In spite of all these interesting features of floating tire breakwaters, to date, no systematic studies have been carried out on the environmental impact of deployed FTB's nor has much been done quantitatively on the effectiveness of such structures as fishing reefs or habitats. To this end, a study was proposed by the Lake Erie Institute for Marine Science and subsequently funded by the Pennsylvania Department of Environmental Resources, Division of Coastal Zone Management relative to evaluating the potential impact of installing an FTB on water quality and fisheries resource. This report presents the results of a one year environmental impact study on a new FTB installation. This installation was on the south shore of Presque Isle Bay, Erie, PA. The particular FTB installation was coordinated by Dr. Robert Pierce, Associate Professor of Engineering, Pennsylvania State University - Behrend College. Erie, PA., who was principal investigator of this federally funded (FTB Construction and Engineering study project) New York Sea Grant Institute program. Details of the subject FTB are presented in Appendix 1.

2.0 EXPERIMENTAL

2.1 Site Location

Presque Isle Bay is a natural bay located in the eastern basin of Lake Erie bounded on the southern shore by Erie, PA, and by Presque Isle State Park on the northern shore. The 40 x 125 foot FTB described in Appendix 1 was systematically assembled, positioned and anchored in a cove on the south shore of Presque Isle Bay, Erie, Pennsylvania during the time period July 25 to August 26, 1982. The site was west of the Erie Municipal Water Plant at the foot of Chestnut Street (see Figure 1). The FTB was positioned 260 feet off shore at its closest point in water 8 to 9 feet deep. At this location, the FTB is

FIGURE 1

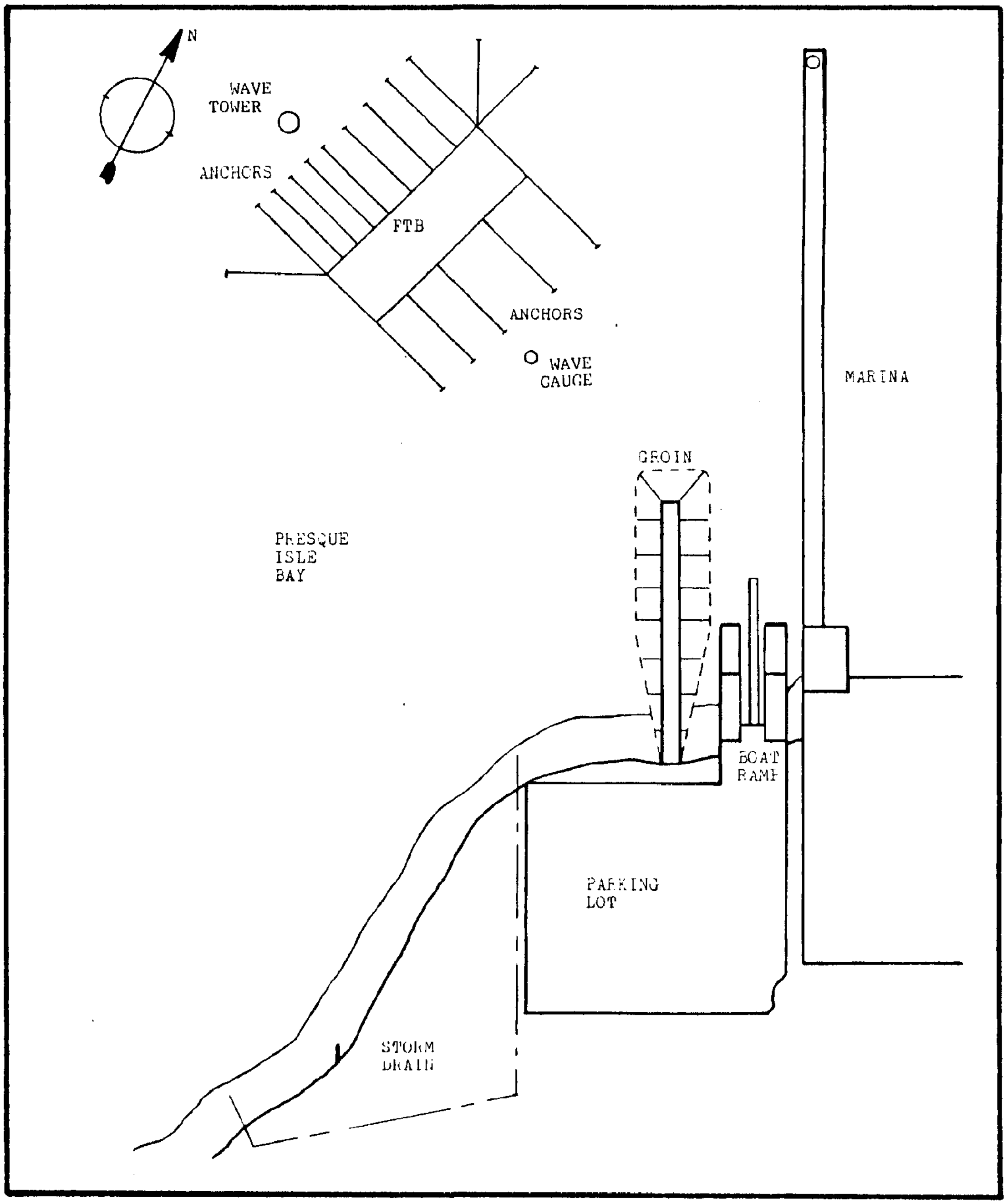

CHART SHOWING FTB LOCATION IN PRESQUE ISLE BAY

potentially subjected to an unobstructed wind/water interface length (fetch) of 2.5 miles from a north westerly direction. The Presque Isle Bay area is characterized by prevailing westerly winds. A fetch of 2.5 miles from the northwest direction, the predominant wind direction for storms on Lake Erie, produces the highest observed waves (2.5-3 feet high) in the vicinity where the FTB is located.

From a geological standpoint, a significant amount of rubble and large rock fragments are present on the bottom and shoreline of the bay. Large rock fragments were placed along the shoreline in 1968 by the City of Erie in order to reclaim a portion that had been eroded in a major storm and to protect it from subsequent wave damage. A groin consisting of large rock fragments was constructed at the site in 1980 to protect the new public boat launching ramp and float stage complex that presently occupies the waterfront at the foot of Chestnut Street.

This coastline area is characterized by a 150-200 foot shoreline plateau, rising 4 to 5 feet above mean lake water level. The plateau serves in part as a parking lot for those using the public boat ramp. This plateau region terminates with a 30 foot high bluff consisting of Pleistocene glacial sediments (see Figures 2 and 3). No streams flow into the bay in the immediate area; however, a small municipal storm drain does exit into the bay, about 200 feet west of the groin (shown in Figure 1).

Overall, this site was ideal for the intended FTB study and for the engineering study proposed by Dr. Pierce. The advantages of this site are summarized in Table 1.

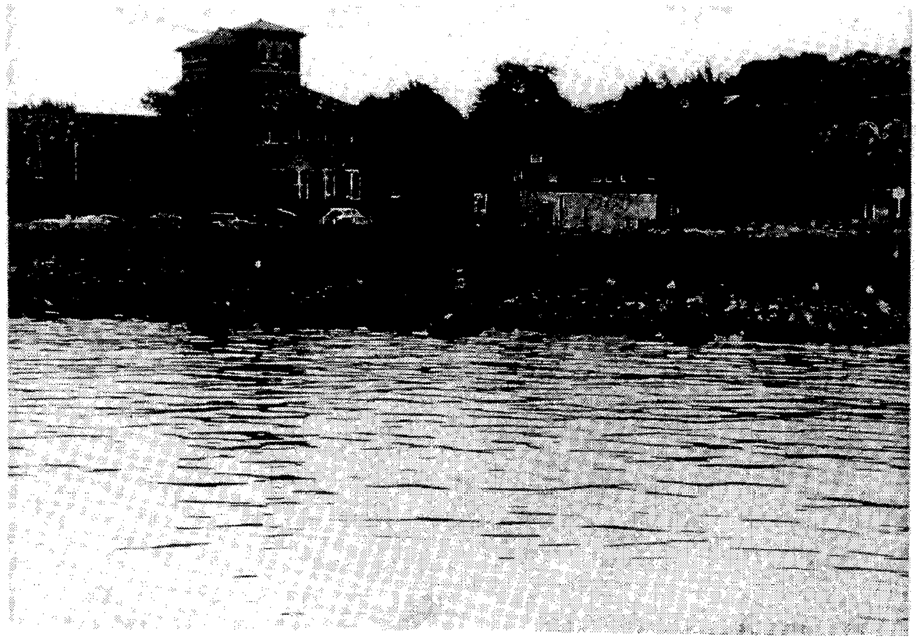

Figure 2. FTB site looking south - toward shore.

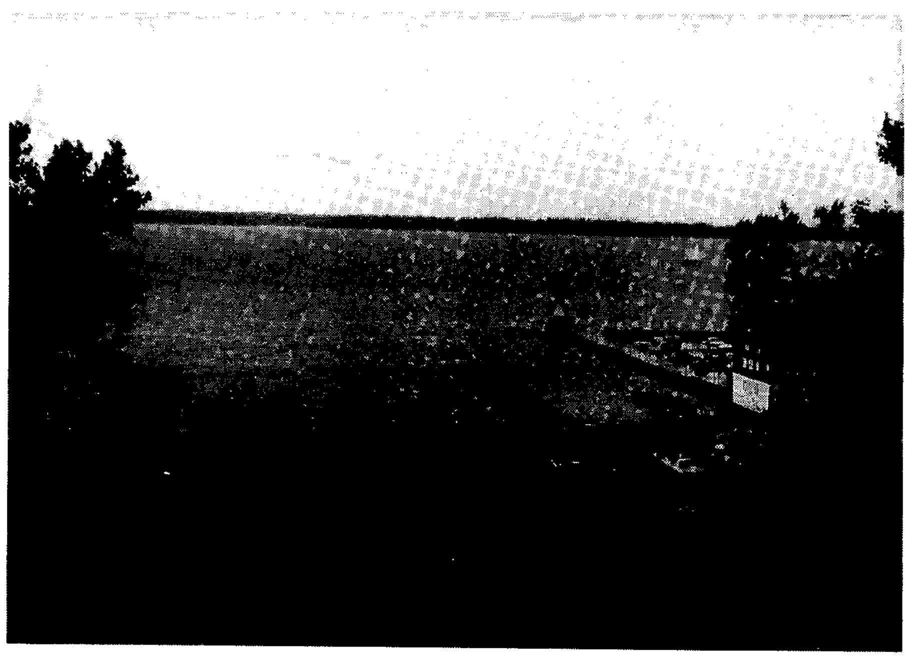

Figure 3. FTB site looking north - toward Presque Isle Peninsula.

TABLE 1: Summary of Features and Advantages

of Selected FTB Site Location.

1. Location technically appropriate for breakwater/water wave attenuation experiments. Semi-protected waters, open to the northwest (2.5 mile fetch) the direction of the majority of the storm winds and waves. It is not open water. If the installation holds up well in Presque Isle Bay, from an engineering viewpoint, then consideration will be given to installing FTB's in the more severe wave climate of Lake Erie.

2. Located in close proximity to the City of Erie Water Department and the City of Erie Recreation Department's new public boat ramp (see Figure 1). This offers good visibility by the public, convenience for fishermen. Some project surveillance and security for the structure are also offered by this location.

3. FTB affords some wave protection to the municipal boat ramp from the northwest exposure as significant wave attenuation has been noted at the boat ramp as a result of this installation.

4. Site has excellent visibility from shore. A 30 foot bluff overlooks the site. The FTB is well positioned for a public demonstration project.

2.2 Technical Measurements

Chemical, physical, and biological property measurements were made using a basic instrument for the on-site chemical and physical water quality measurements called the Hydrolab Water Analyzer. A description of this instrument is presented in Appendix 2. Hydrolab measurements were made at various times as a means of monitoring the pH, dissolved oxygen, conductivity, temperature and ORP (oxidation-reduction potential) of the water around the breakwater, and also at various locations in Presque Isle Bay away from the breakwater. These latter locations were studied to develop a set of baseline (for comparison) data for the experiments.

The measurement site locations are described in Table 2 and are shown in Figure 4.

TABLE 2: DESCRIPTION OF SITE LOCATIONS FOR

HYDROLAB WATER QUALITY MEASUREMENTS

(see Figure 4 and 5)

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FTB MEASUREMENT LOCATIONS

1. At the front (northwest, facing the open bay) perimeter region of the FTB.
2. At the back (southeast, facing the shore) perimeter of the FTB.
3. Under the central section of the FTB.[a]

BASELINE MEASUREMENT LOCATIONS[b]

1. Site of the FTB before it was installed.
2. A region 40 to 50 feet in front of the FTB.
3. Toward the middle of the bay about 500 feet from the FTB.
4. At the end of the groin (accessible from shore).

===

[a] With this particular FTB design, one is able to walk on the tire cladded tube portions of the structure because of their positive buoyancy. Measurements within and under the FTB were therefore possible.

[b] It was learned that the chemical, physical and biological properties of the bay water in all the described locations were very similar. This means the bay waters are, in general, uniform in this general area of Presque Isle Bay.

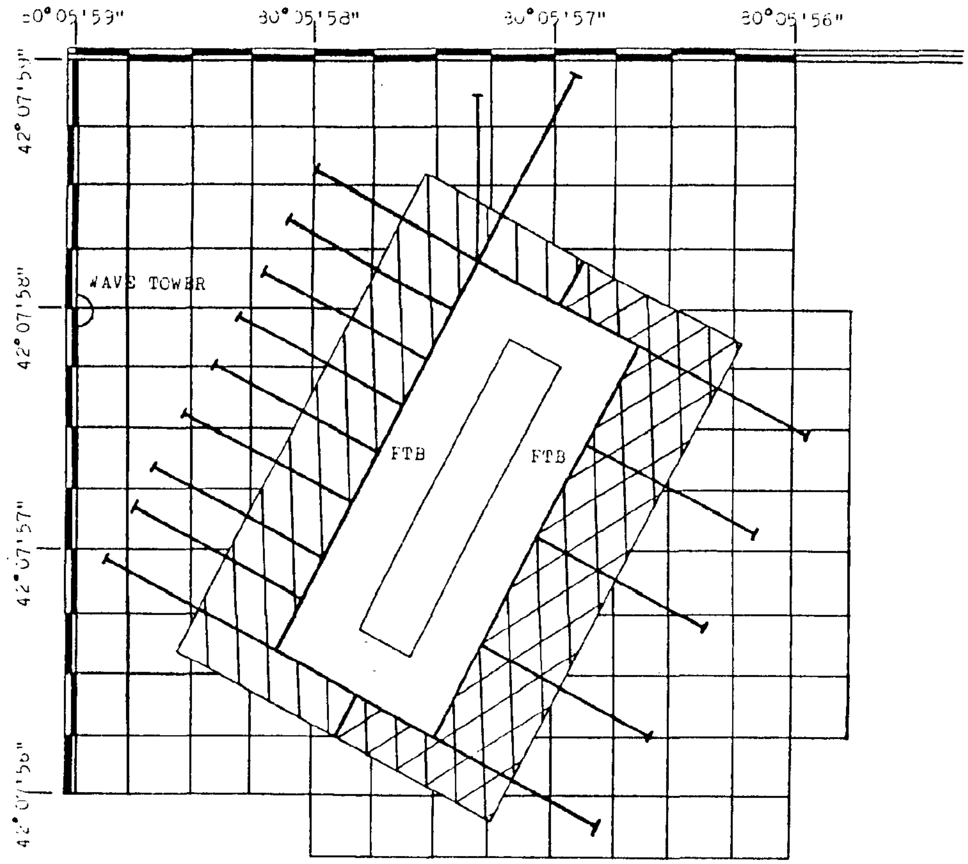
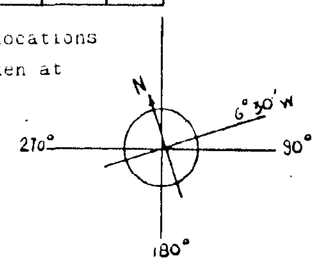


Figure 4 Diagram of FTB showing measurement locations in the area. Baseline data were taken at least 100 ft. from this structure



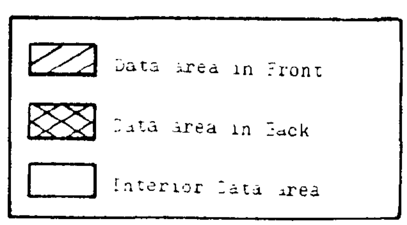
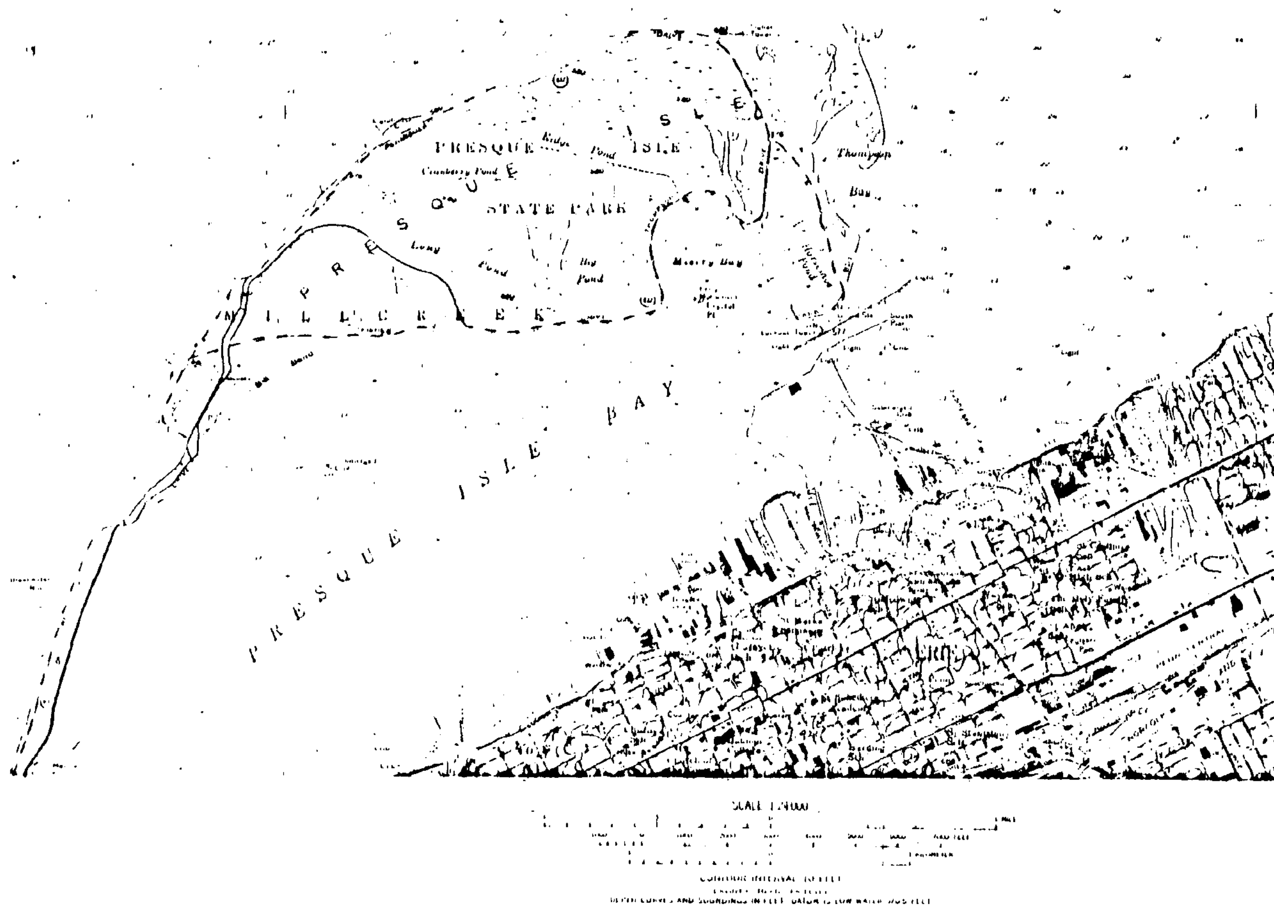


FIGURE 5



Erie North, Pa. 7 1/2' Quadrangle
1957 Photorevised 1959

2.3 Fish Population Studies/Observations

Quantitative methods to determine fish populations are an involved and long term undertaking. SCUBA diving is involved on a routine basis and a physical counting of fish is required. To be meaningful, these studies must span at least a four year period.[10] Such a quantitative study of fish population was not carried in this reported work. Even if time and funds were available to do such studies, they would be difficult to carry out due to the low transparency of the water in Presque Isle Bay, especially at the site of the FTB. SECCI DISK water transparency readings ranged from 3 to 4 feet during the entire period of the measurement program indicating that the water was too turbid for any quantitative measurement of fish population. Because of this, it was judged by the principal investigator that only a qualitative fish population study could be conducted. Conclusions could be made based on direct sport fishing activity in the area. To this end, members of the LEIMS staff were encouraged to fish the area around the FTB from time to time and record the amount of fish activity, species, number caught, and average size of the fish. When appropriate, other fishermen (See Figure 6) fishing the area were asked about their catch. These data from anonymous fishermen were also recorded and compared with the results obtained by LEIMS personnel. By this means, a judgement or opinion as to the effect the FTB installation had on fishery resource could be made.

2.4 Public Awareness Comments

In an effort to qualitatively assess the public response to the subject FTB installation, whenever convenient, the opinions of nearby fishermen and boaters using the boat ramp at the Chestnut Street launch area were solicited. Their comments were compiled and are used in this report.

Figure 6. Local fishermen utilizing the calm water behind the FTB for a more comfortable outing.

Figure 7. Sea gulls perched on a segment of the FTB.

3. RESULTS AND DISCUSSION

3.1 Chronological Qualitative Assessment

Since July 1982, the month and year the first FTB modules were anchored in place at the FTB site, a qualitative evaluation of the installation was made. Visual observations were made every month for one year from July 1982 to July 1983. A chronological review of these observations follows:

July 1982 - First FTB modules anchored in place. Tires free of growth. No visual environmental effects observed.

Aug. 1982 - Remainder of FTB modules anchored in place at FTB site. Some slight algae growth on tires put in water in July. FTB effectiveness as water wave attenuator first observed. Habitat for sea gulls observed. (See Figure 7)

Sept. 1982 - Attraction of the FTB as a sea gull perch remarkable.

Oct. 1982 - Algae begins to regress. Gulls not as prevalent.

Nov. 1982 - Remaining algae turns brown. Few gulls remain.

Dec. 1982 - Ice forming in FTB area, no ice around tires.

Jan. 1983 - FTB locked in the ice, ice dunes formed on front section of tires. Lifting of front end of breakwater was noticed. (See Figure 8)

Feb. 1983 - FTB locked in ice.

Mar. 1983 - Ice melted around FTB before significant remaining ice pack occurred. (See Figure 9)

Apr. 1983 - Gulls return.

May 1983 - Algae begins to grow and cover exposed areas between tires.

June 1983 - Algae reaches peak growth, ducks begin to congregate and game fish are observed around structure. (See Figure 10)

July 1983 - Ducks and gulls cover structure, small fish seen between tires.

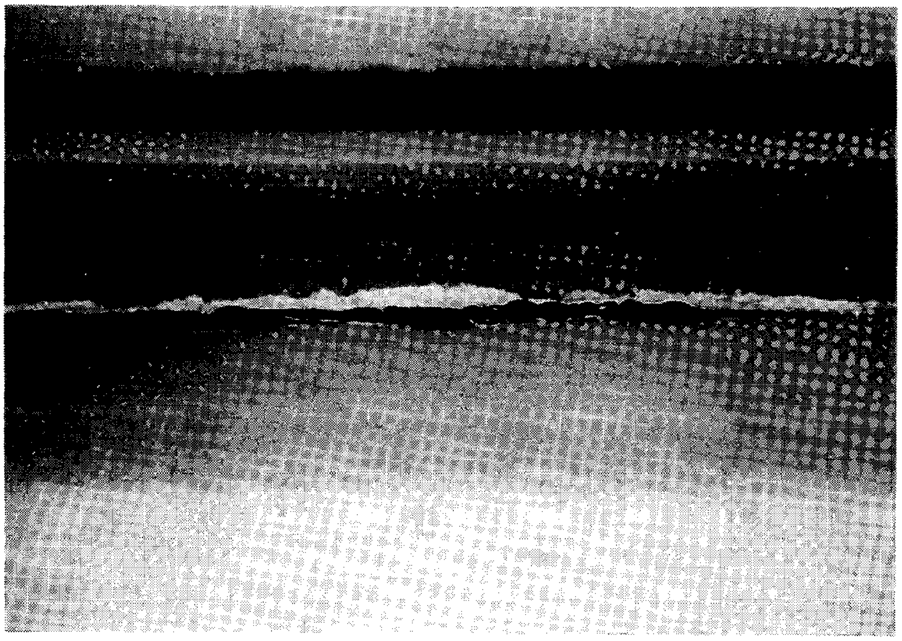


Figure 8. FTB locked in ice with ice dunes formed on leading edge.

Figure 9. Early ice melting around FTB due to black body radiation absorption effects.

Figure 10. Algae growth on the tires in early June 1983.

3.2 Chemical, Physical and Biological Assessment (Hydrolab Data)

Numerous water quality measurements were taken throughout this study. These data were taken at a variety of locations as described in the experimental section of this report. However, one did observe scatter in the data within a day's readings as well as on a week to week basis. Smooth trends in the data were not observed. The following discussion therefore, presents only general trends and the conclusions are speculative. Such results can only be substantiated by obtaining still more data in a prescribed, systematic manner over a long time period. The following general trends in the hydrolab data are presented:

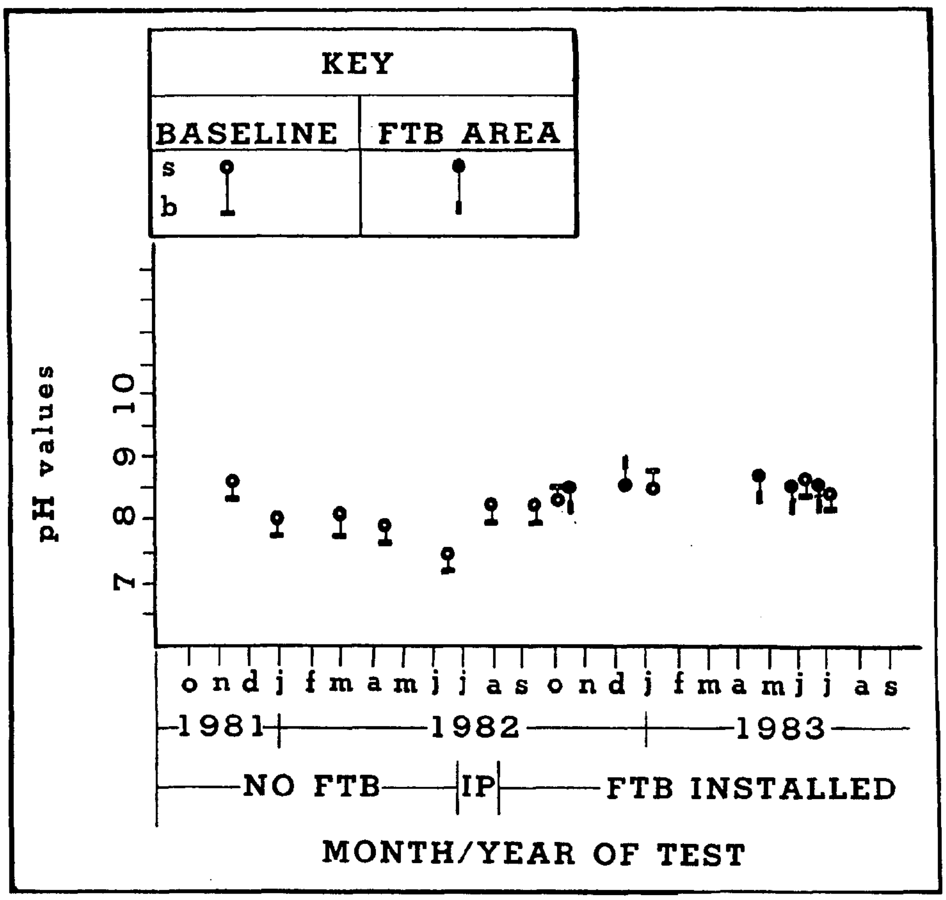
A. pH Changes During the FTB Study Period.

A plot of representative pH values versus month/year of testing is presented in Figure 11. Throughout the period of testing (November 1981 to July 1983) the pH was generally in the alkaline range of 7.1 to 8.9, with the average being somewhere near 8.4. The pH was generally lower at the bottom than at the top layers of the bay water. In general, the pH profile within the FTB site area followed the trend of the baseline data. There was no evidence that the pH of the water in the FTB site area was altered by installing the floating breakwater.

The pH of natural waters is governed by the extent of CO_2 dissolved in the water as well as the presence of dissolved Bicarbonate ions that hydrolyze into OH^- ions. Natural waters of open lakes generally range in pH from 6 to 9. Calcareous hardwater lakes commonly have pH values of about 8; such a condition was observed during this present Presque Isle Bay study. Fish are rather tolerant of pH changes. A range of pH from 6.7 to 8.6 will generally support a good crop of fish. Within this range, pH does not effect growth, reproduction and physical well being of fish.

FIGURE 11

CHANGE IN pH PROFILE
DURING FTB STUDY PERIOD
comparison with baseline values



B. Dissolved Oxygen (DO) Changes During the FTB Study Period.

A plot of representative dissolved oxygen (DO) versus month/year of testing is presented in Figure 12. The DO ranged between a high of 13.4 and low of 8.2 with higher values occurring when the water was colder and the lower values occurring during the summer months. In the vicinity of the breakwater, the DO values appeared to be higher at the surface. In general there appears to be no significant difference between data in the FTB area when compared with the baseline area.

The solubility of oxygen in water is affected non-linearly by temperature; colder water can dissolve more oxygen. Concentration of oxygen in the water is one of the most important environmental variables to which fishes must adjust. Under natural conditions, fishes seem to thrive best in water oxygen concentrations of around 9 ppm. Oxygen concentrations as high as 40 ppm can be tolerated by some fish species for a short period of time. The lower limit for oxygen concentration for fish habitation is generally considered to be 5 ppm.

C. Water Temperature Profile During the FTB Study Period.

A plot of representative water temperature data taken during the study period are shown in Figure 13. The data reflect the normal seasonal temperature variations. Overall, there was no detectable difference between the water temperature in the vicinity of the FTB versus the baseline. However, not shown in Figure 13 is the observation that during the middle of June 1983, a series of five sunny, warm days occurred. During this period it was observed that the water temperature at the bottom under the FTB was 3 degrees centigrade lower than at the top water layers within the FTB structure itself. The baseline temperature (top and bottom layers) did not show this large top to bottom temperature difference. It has been concluded that the FTB provides an aquatic shading effect. The sun cannot penetrate the FTB structure to warm the bottom

FIGURE 12

CHANGE IN DISSOLVED OXYGEN PROFILE
DURING STUDY PERIOD

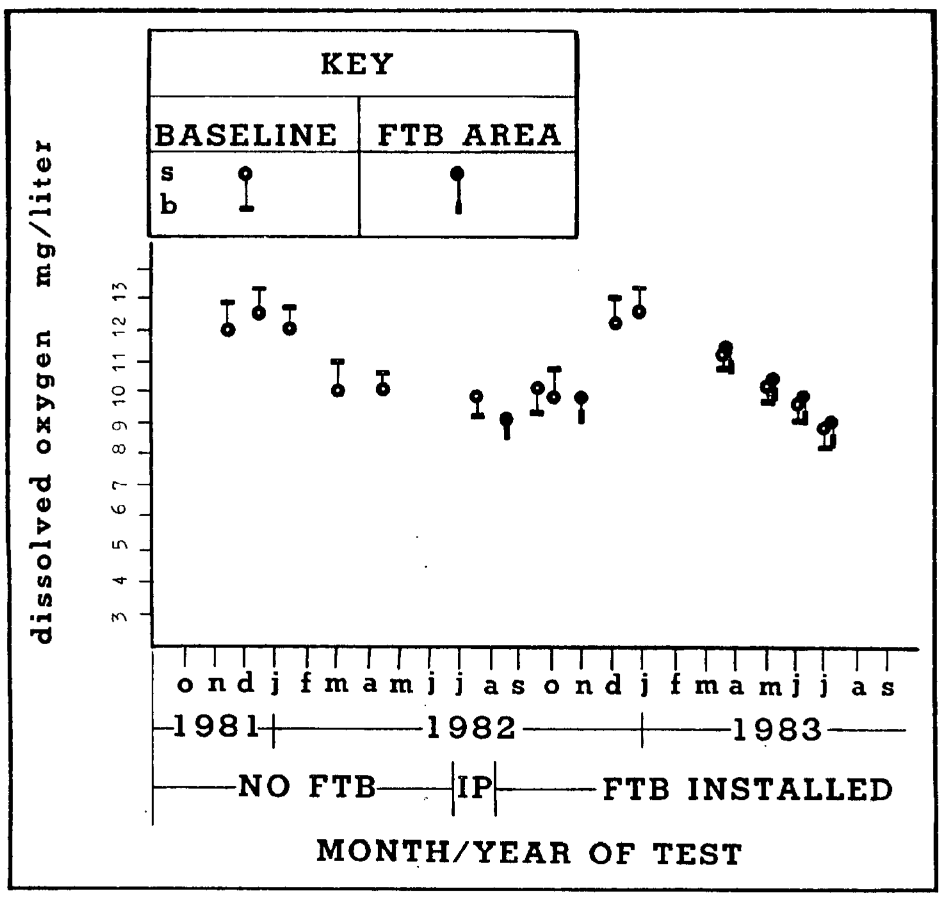
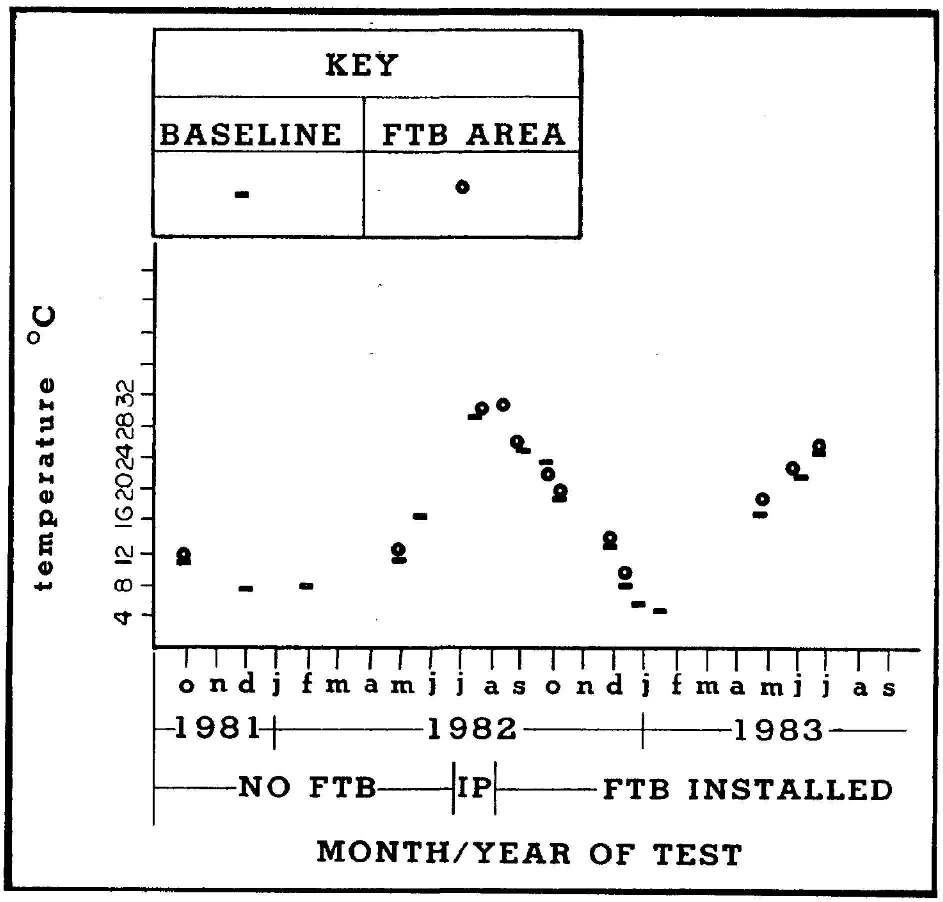


FIGURE 13

WATER TEMPERATURE PROFILE IN VICINITY OF FTB COMPARED TO BASELINE



layers of the water. There is therefore a lag in the rate of heating of the water under the FTB by the sun under the FTB. Such an effect is most likely dynamic and due to diffusion and water circulation.

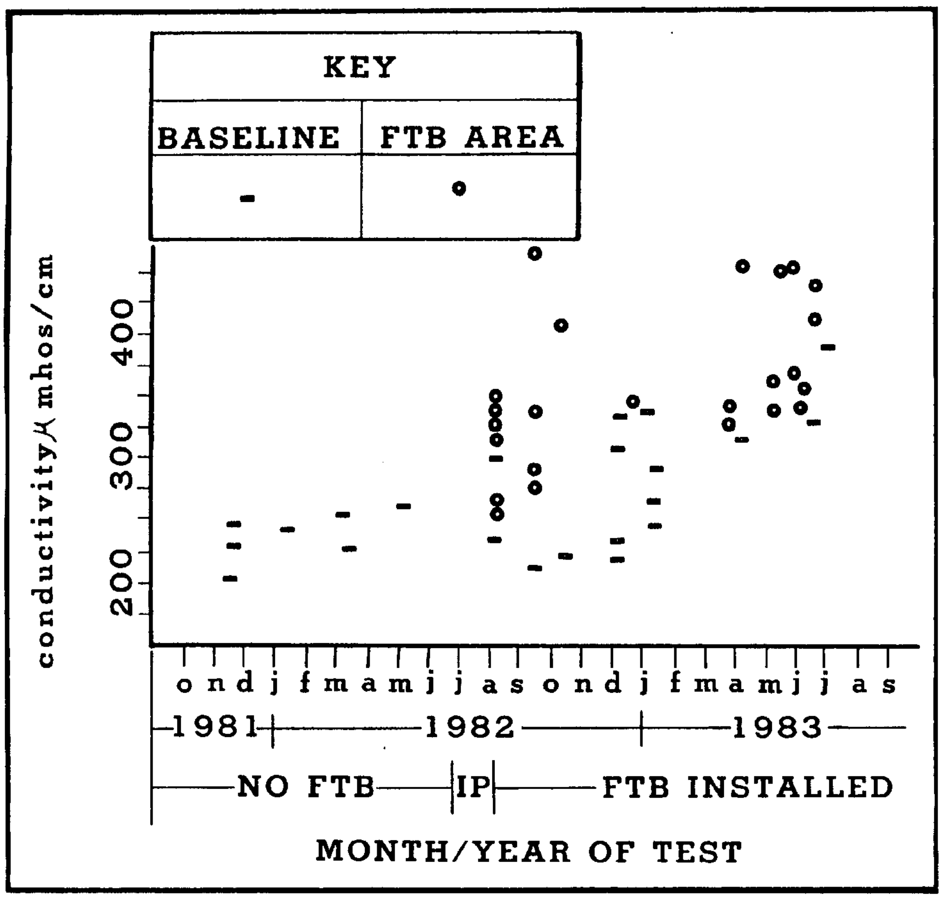
The body temperatures of fish is determined within a few tenths of a degree by the temperature of the water in which they live. The level of activity of cold-blooded animals is determined by temperature. At the lower temperatures, such animals are less active. The temperature range is generally 6° to 35°C. Some fish can survive at 0° to 3°C at a lower temperature. Other species can survive at higher temperatures up to 37°C. As a general rule, heat death of fish occurs at 40°C.

D. Electrical Conductivity Profile of FTB Site/Baseline Waters During Month/ Year Test Period.

Representative data showing the variation of electrical conductivity of the Presque Isle Bay waters during the test period are shown in Figure 14. The electrical conductivity of aqueous media is a very sensitive measurement, almost too sensitive to interpret with any confidence. The subject electrical conductivity measurements can be interpreted as an indication of the amount of dissolved ions (electrolyte) in the water. From this, it was observed that the measurements taken during the initial installation period (August to October 1982) indicates a higher electrical conductivity of the waters around and in the FTB location compared to the electrical conductivity of the "baseline" waters. As indicated by Figure 14 the baseline conductivity during the August - October 1982 period was 200 to 280μ mhos/cm. In the vicinity of the FTB during the same period, the conductivity of the water ranged from 250 to 500μ mhos/cm. It is felt that this is a real difference in spite of the wide scatter of the data. One explanation could be that electrolyte is being leached out of the scrap tires in the FTB structure. It is possible that road salt from the tires and

FIGURE14

ELECTRICAL CONDUCTIVITY PROFILE IN VICINITY OF FTB RELATIVE TO BASELINE



alkaline (lime) minerals from the rubber belting used in the construction of the FTB is being dissolved out of the material. This speculation is somewhat supported by the observation that at present (spring and summer 1983), the electrical conductivity of the waters around the FTB and the baseline are similar. There is now no difference suggesting that during the winter months this electrical conductivity difference effect has dispersed itself by the natural dynamics of the wind/wave/current action of the Presque Isle Bay waters.

The conductance of common bicarbonate-type lake water is closely proportioned to concentrations of the major ions dissolved in the water. Such ions as Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, CO_3^{-2}, SO_4^{-2}, and Cl^{-} are the most common ions that lead to the conductivity of natural waters. In low salinity water, the conductivity is very sensitive to even slight changes in ionic strength of the water.

With reference to the physiology of the fish life, from salts ingested sodium, potassium, and chloride ions are absorbed in the gut; only small amounts of these absorbed ions can be eliminated in the small volume of urine produced. Calcium, magnesium, and sulfate ions become concentrated in the residual alkaline intestinal fluid; the cations are eliminated as insoluable oxides of hydroxides.

E. Oxidation-Reduction Potential (ORP) Profile of FTB Site Waters Relative to Baseline Waters During the Test Period.

In this measurement, the ORP value taken throughout the period can only be interpreted as to whether the water tested is a chemical oxidizer or a reducer. During the entire study the bay waters for both baseline and FTB site locations indicated a chemically reducing trend. Such a condition was almost universal. However, when the FTB was first installed at the site, late July to the middle of August 1982, some Hydrolab ORP readings were obtained when the waters around the FTB were observed to be in a state of a chemical oxidizer. It is not certain if this transient observation is real since the data were scattered during this measurement period.

The REDOX potential of natural lake waters can be considered to be a means of determining its degree of eutrophic character. Highly eutrophic lakes are reducing in nature. Chemically, the reduced state of such lakes can be attributed to the bacteriological reduction of sulfate ions to sulfides; the reduction of nitrates into nitrites and ammonia can also occur. The relationship between the REDOX nature of lake water on fish life is complex.

F. Metallic Ion Concentrations.

Ionic concentrations of calcium (Ca), magnesium (Mg), and sodium (Na) were determined with a Perkin-Elmer atomic absorption spectrophotometer. These three ions together with potassium (K) are the major cations which determines the total salinity of inland waters. The average concentrations of the calcium, magnesium, and sodium ions in the FTB area prior to installation of the FTB were as follows:

Calcium - 33.30 ppm

Magnesium - 7.23 ppm

Sodium - 14.31 ppm

There were no substantive differences in the concentrations of these ions between the baseline stations, and the site of the FTB.

The following concentrations (ppm) were determined for June 17, 1983 sampling date:

		Front FTB	Middle FTB	Back FTB	Central Back FTB
Calcium	top	57	36	33	31.0
	bottom	52	42	36	33.0
Magnesium	top	8.2	8.6	7.6	7.4
	bottom	8.2	9.3	7.8	7.4
Sodium	top	14	15.1	13.0	14.0
	bottom	14.2	14.8	13.5	15.5

These concentrations of calcium, magnesium, and sodium compare favorably with those determined by the Erie County Health Department.[13] The concentrations of calcium at the front and middle of the FTB possibly indicates that some calcium could be leaching from the rubber belting and the tires, but most of the calcium and sodium in Presque Isle Bay comes from the usage of calcium and sodium chloride during winter months to reduce road icing. Calcium concentration values in the 50 ppm range have been reported at point sources (near the mouth of some streams) by the Erie County Health Department (1978-79). The toxicity of calcium, magnesium, and sodium in the quantities measured is relatively harmless to all organisms.

3.3 Qualitative Observations on Fisheries Resources at the FTB Location.

During the summer of 1981, Lewis[11] studied the area in the bay where the FTB was to be installed and reported the following:

. the bottom consisted of shale bedrock with little or no sediment on top

. a few small fractures in the shale were filled with sand

. fish species found were perch, various species of sunfish, rock bass, yellow pike, drumfish (aplodinotus grunniens), and various species of catfish.

*Appendix 3 lists scientific names of fish mentioned in text.

Lewis found that the numbers and species of fish changed daily, and that most of the fish were not fully grown. The observation by Lewis in 1981 also followed for the spring and early summer of 1982. Since the FTB installation was not completed until late August of 1982, it was too short a period to expect one to evaluate the impact that the FTB might have on the fishing in this area. However, in qualitative fishing studies conducted in the spring and summer of 1983, some new observations were made by Lewis.

A number of large rock bass* were found inhabiting the area. They were not found directly around the floating structure but appeared to be around the anchors. They seemed to be fully grown and compared in size to other rock bass found in the bay.

Although it is said that the perch population has declined in the bay, Lewis reports that a number of good size perch have been removed from the site. These fish were not as numerous as in years past. They appeared to have better color and were much larger than ones caught previously. The baseline area behind the FTB still supports the smaller perch which are taken by the shore fishermen. The shore area is heavily fished most of the year, so the number of large, slow migrating fish is small.

Fish such as crappie and sunfish surround the breakwater. They tend to stay close to the structure. The breakwater provides cover as well as a good food supply of small minnows and a wide variety of water insects.

A large number of small mouth bass were observed in the area during the spring of 1983. The average size was 12" weighing approximately 1.25 pounds. These bass were feeding on the minnows that surrounded the structure. No large size bass were seen in the area but there were a number of small bass (less than 6") around the FTB. These bass should remain in the area because of the ample amount of food.

The number of scavenger fish (carp and drumfish) has not changed in the past year. The size of these fish has increased. The debris that falls to the bottom around the FTB has apparently attracted larger fish.

There have been no catfish seen so far this year in the FTB area. In years past there were a fair number taken from the site. It cannot be determined if the FTB has had any effect on these fish.

In general, the most notable change in the area fish population has been the increase in the number of large rock bass. It appears that the replacement of the bottom cover by the floating breakwater has had no negative effects on the fish. The smaller fish such as baby minnows and others appear to have adjusted well to the change. No fish eggs have been spotted around the breakwater, but they were noticed on tubes that were being stored in the water for use during construction. The long term effect of this floating structure and hardware cannot be made at this time.

4.0 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Conclusions

Based on this study, several general conclusions can be drawn:

1. The Presque Isle Bay floating tire breakwater installation of 1982 has had no significant effect on the water quality in the area of the installation.
2. Uniformity in pH, dissolved oxygen, electrical conductivity and temperature measurements existed throughout the testing area prior to installation of the FTB.
3. Behavior of the pH, dissolved oxygen and temperature parameters after installation differed only slightly from the baseline trends.

4. The electrical conductivity of the water in the vicinity of the FTB increased during the first three months of study after the FTB was installed (August to October 1982). The electrical conductivity of the water in the FTB area was on the average measureably higher than the baseline values. This effect is believed to be due to electrolyte leaching out of the tires and rubber belting that was used in the construction of the FTB. The observation was transient since in the spring and summer of 1983 (9 to 12 months after the installation) the water conductivity data obtained in the vicinity of the breakwater followed background trends.
5. Compared to summer 1982, by qualitative observation and investigation, the fish population in the vicinity of the FTB has increased. In addition to a larger number of fish being caught, schools of small minnows can now be observed in and around the algae growth among the tires.
6. The FTB installation provides some wave protection to the public boat launch facility in the area. From informal opinion surveys concerning the FTB installation, the FTB has been favorably accepted by the boat owners, sport fishermen and general public who frequent this area of Presque Isle Bay.
7. As time passes, more fishermen are observed fishing in the vicinity of the FTB. Some are now fishing in the protected area in the lee of the breakwater when rough water conditions exist on the bay.

Recommendations for Future Consideration

As a result of the experience gained while conducting subject study, several recommendations are in order:

1. The FTB should be further monitored to determine its long range fish propagation characteristics and its attraction as a recreational fishing reef.

2. The extensive algae growth on the structure should be studied for absorption of heavy metals.

3. The breakwater should be expanded to better protect the public launching facility, thereby adding to the recreational value of this prime bayfront area.

4. Shoreline erosion should be monitored to evaluate the long term effect of the FTB as a low cost shore protection device.

5. Further studies should be conducted to determine the ice-FTB interaction during the winter season.

5.0 ACKNOWLEDGEMENTS

The construction and installation of the FTB was completed by the Lake Erie Institute of Marine Science (LEIMS) with a grant from the Federal Sea Grant Office, NOAA, through the New York Sea Grant Institute, Albany, New York. Dr. Robert E. Pierce, a Penn State-Behrend College engineer, served as the principal investigator of the FTB Construction and Engineering study project. The Pennsylvania Division of Coastal Zone Management, Department of Environment Resources funded this presently reported study to determine the potential impact of the FTB on Presque Isle Bay water quality and fishery resources. We thank the Pennsylvania Department of Environmental Resources Division of Coastal Zone management for their support.

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APPENDIX 1

Floating Tire Breakwater Materials and General Design Features

Lake Erie Institute for Marine Science installed the floating tire breakwater (FTB) in Presque Isle Bay upon which the subject water quality study was conducted. Funding for the fabrication and installation of the FTB was obtained from the Federal Sea Grant Office (NOAA) in the form of a 3 year research grant awarded and administered by New York Sea Grant Institute (Albany, New York). Funding was for the purposes of obtaining open water, wave transmission measurements on the structure and assessing its durability in a harsh weather climate. The FTB is of an advanced, heavy duty design employing both large diameter steel tubes and tires in its construction. It is, therefore, more appropriately referred to as a pipe-tire floating breakwater.

Basically the breakwater design consisted of nine tire cladded steel tubes (16 inch O.D. and 40 ft. long) positioned in parallel so that their axes coincided with the dominant direction of wave advance and at a space (center-to-center) of approximately 15 feet. Tires threaded onto rubber stringers, which themselves were attached to selected tires of the tire-clad tubes, filled the space between tubes. The end result was a matrix of densely spaced tires all connected by flexible rubber belts and into which steel tubes were interweaved in a special way. By design, no rigid connections existed between the tires and steel tubes. Tires are held onto the steel tubes by steel retaining lugs welded at each end. The steel tubes provide for a secure mooring line attachment. Details on the fabrication and installation of the 120 ft. by 40 ft. floating breakwater are given in reference 12.

The materials used in the construction of the breakwater included:

.scrap car and truck tires

- .scrap rubber conveyor belting (1/2 to 5/8 inch thick with nylon reinforcement)
- .steel pipes (1/4 to 5/16 inch wall thickness, 16 inch O.D., 40 ft. lengths).
- .cadmium plated bolts, washers and nuts.
- .stranded steel cable.
- .galvanized steel cable clamps and shackles.
- .2000 lb. and 3500 lb. reinforced concrete anchors.
- .polyurethane foam.

Scrap rubber conveyor belting was obtained in widths of 36 and 40 inches from the Lorain Ohio Plant, U.S. Steel Corp. The conveyor belt was removed from a system which transported crushed limestone used in the steel making process. After continued use, the limestone caused the surface of the belting to harden and craze leading to noticeable entrapment of the material. This necessitated the wearing of gloves to protect the skin while working with the belting. The belting was slit into strips approximately five inches wide and used as a tire stringer and tire binding material. It is expected that this surface contaminate leached into the water upon installation of the breakwater.

Scrap truck tires used in the construction of the breakwater may also have had some effect on the water quality. Many of the tires were accumulated during the winter months and showed evidence of road salt and other road surface accumulation. No attempt was made to clean the outer portions of the casings before installation of the device.

Additional information about the FTB project carried out by Dr. Robert Pierce is presented in the following paper. The paper was the subject of a presentation by Dr. Pierce at the Oceans 83 Conference, San Francisco, California, August 29 to September 2, 1983.

FABRICATION, INSTALLATION AND FIELD TEST PROCEDURES
FOR A PIPE-TIRE FLOATING BREAKWATER

Robert E. Pierce

Behrend College, The Pennsylvania State University, Erie, PA 16563
and
Lake Erie Institute for Marine Science, Erie, PA 16507

Abstract

A pipe-tire floating breakwater is currently being field tested in Presque Isle Bay, Erie, PA. Subassemblies of the breakwater were fabricated in three different configurations, two of which are being reported for the first time.

Techniques are described for the launching and towing of the breakwater subassemblies to the mooring site using standard marina equipment. Final on-site assembly of the breakwater sections into an integral unit was facilitated by the positive buoyancy characteristics of the truck tire-cladded pipes which permitted personnel to move about on the structure.

A field test site has been configured to obtain the wave transmission characteristics of the device and uses newly developed instrumentation for measuring, in real-time, the direction of wave advance, significant wave height and significant wave period parameters. Observations are reported on the behavior of the breakwater during the winter season.

Introduction

This report describes another phase in the continuing effort to obtain engineering measurements on floating breakwater systems fabricated principally from scrap tires. One of the first serious attempts to obtain wave transmission and mooring force data on a prototype scale floating tire breakwater (FTB) section was carried out on an assembly of Goodyear modular design[1] as a joint effort between the Army Corps of Engineers Coastal Engineering Research Center (CERC) and Lake Erie Institute for Marine Science (LEIMS). The LEIMS organization provided the breakwater section, the anchoring system and the mooring force measuring equipment, while CERC conducted the tests in their large wave flume using CERC wave measuring instrumentation. Pierce and Lewis[2] of the LEIMS organization reported on the general aspects of the test program and Giles and Sorenson[3] of CERC reported the detailed engineering data. These tests were carried out during the summer and fall of 1977.

In 1979, V. Harms[4] tested a prototype scale pipe-tire floating breakwater section in the same CERC wave flume. The pipe-tire configuration dubbed PT-1 is a heavier design featuring improved front-to-back structural rigidity. It is a truck tire design and utilizes a denser packing of tires than the forerunner Goodyear modular units.

Recognizing the need to obtain FTB performance data in a typical field situation, New York Sea Grant Institute funded the LEIMS organization, commencing in 1980, to construct and field test a pipe-tire floating breakwater. The selected test site in Presque Isle Bay, Erie, PA. was to be instrumented to obtain transmission data on the structure as well as to ascertain its durability in the harsh weather environment. During the summer of 1982, a 120 ft. (length) by 40 ft. (beam width) pipe-tire floating breakwater was installed approximately 360 ft. off the south shore of the bay (see Figure 1). The device was located off City of Erie property and was positioned to afford some wave protection to boaters using the public launching ramp aft of the FTB. The leading edge of the breakwater has a northwest exposure, the direction of prevalent wind.

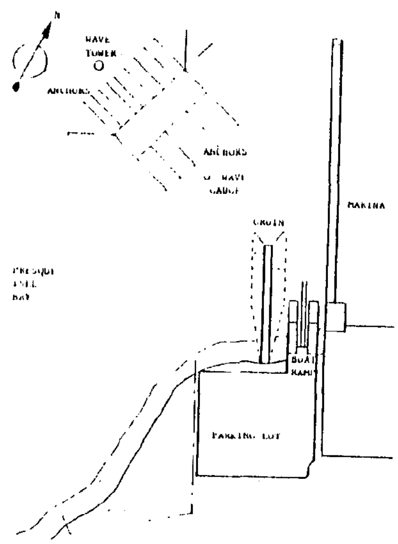

Figure 1. Field test site in Presque Isle Bay.

In order to obtain wave transmission data, the direction of wave advance must be known. For this purpose a new and novel instrument[5,6] has been developed capable of measuring wave direction,

This research was sponsored by New York Sea Grant Institute under a grant from the Office of Sea Grant National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. The U.S. Government (including Sea Grant Office) is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation appearing hereon.

significant wave height and significant wave period - all in real-time. A sensor array is supported in a newly developed open-truss, space-frame, type tower[7,8] designated as a wave tower in Figure 1. Microprocessor-based signal processing circuitry is mounted on top of the tower and above water level. More recently a digital data transmission capability[9] (FM mode) has been added to provide a wireless data link to the shore-based microcomputer system used for final analysis and display of results.

This paper details the construction, launching, and towing techniques associated with getting the breakwater sections assembled and positioned at the field test site for final connection into an integral unit.

A description of the instrumented test site is included along with observations of breakwater behavior during the harsh winter months.

Floating Breakwater Design

Rigid steel pipes are used in the structural design of the floating breakwater. Truck tires are threaded onto 16 inch diameter by 40 ft. long steel tubes yielding a rubber cladded structural member to which stringers of tires are attached. To form a floating breakwater, the tire-cladded tubes are aligned in parallel with their axes coincident with the dominant direction of wave advance utilizing a center to center spacing in the range of 13 to 17 feet. Tire stringers are then attached between the tire-cladded tubes to fill up the space with a tire maze, which will hereafter be referred to as the tire matrix. Attachment of the tire matrix to selected tires on the tire-cladded tubes is effected using strips of rubber conveyor belting. The result is a floating breakwater with flexible rubber connections at all tire interconnection points and with the steel tubes interleaved into but not rigidly attached, to the tire structure.

Tires are held on the tubes by welding steel retaining lugs to each end. All but 2.5 to 3 per cent of the space between the retaining lugs is covered with tires. The remaining free space permits shifting the tires back and forth for threading of the tire matrix binding belts.

All mooring lines are attached to the steel tubes providing for a stronger, more secure connection. Steel tubes interleaved into the structure in this manner results in a less flexible structure in the direction of wave advance than is realized with an all tire floating breakwater. In addition, a more dense packing of tires is achieved with the pipe-tire floating breakwater than with the more conventional all tire Goodyear design floating breakwaters. Both factors contribute to its enhanced wave attenuation characteristics.

The tire stringers forming the tire matrix are of three different configurations. The first design (PT-1) is constructed by simply threading truck tires onto rubber belt stringers spanning the region between two tire-cladded tubes. This results in a matrix tire alignment perpendicular to those on the tubes with the curved tread surface positioned in the direction of wave advance. Since these tires are not bound together in any way except for being on the same rubber belt stringers, the matrix tires are rather loosely coupled. Four sections of the floating breakwater were fabricated using the PT-1 design. Eleven stringer rows were used for each section with ten tires on each stringer. A PT-1 section is shown in the launching well in Figure 2.

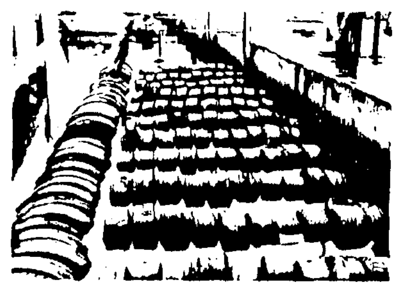

Figure 2. PT-1 section shown in launching well.

Truck tires bound together in a Goodyear modular arrangement to form a stringer were used in the fabrication of one section (see Figure 3).

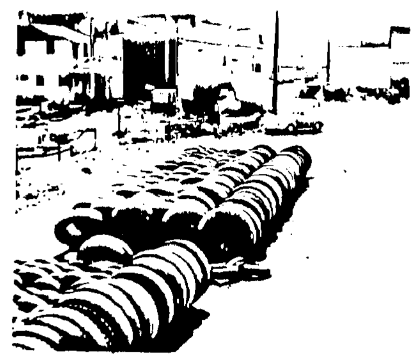

Figure 3. PGYM-1 section (center of photo).

This new design was dubbed PGYM-1 (Pipe-Goodyear Module Design 1). Thirteen tires are used in the stringer which is also a module of 3-2-3-2-3 tire arrangement. A stringer of this design, when properly attached at the ends, is a stiffer configuration and presents additional resistance to twisting modes. This construction results in a matrix tire alignment directing the side of the tire (or rim opening) to the direction of wave advance.

Three tire matrix sections of the breakwater were fabricated using car tires bound together in Goodyear modular arrangements. This new design (see Figure 4) is dubbed PGYM-2 (Pipe-Goodyear Module Design 2). Here two standard 18 tire Goodyear modules are fabricated and then joined together at their ends using coupling tires to form a tire stringer of the matrix. The finished stringer is a single module of 6-5-6-5-6-5-6 tire arrangement. (Two 18 tire modules plus 3 coupling tires.)

All tire binding belting used in the construction was cut to a width of 5 to 5½ inches. Belting thickness was in the range of 1/2 to 5/8 inch and contains

4 or 5 plys of nylon cord. Four holes, in a rectangular array, are punched at each end of a belt. Cadmium plated bolts (3/8 inch diameter thread) with 2-one inch diameter washers and hex nuts are used to fasten all belts.

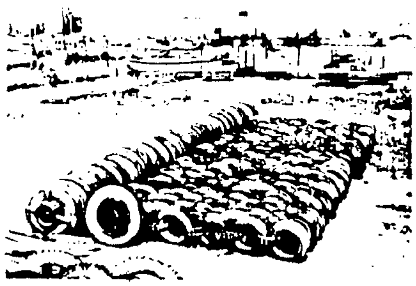

Figure 4. PGYM-2 section.

The end tires of the group on the pipe between retaining lugs are secured to single tires placed outside the lugs using short belts. This partial shielding of the steel lugs was considered necessary to protect the work boat from unnecessary damage.

Three large car tires joined with rubber belting are used in the front mooring lines as a shock absorber (see reference 4). Grease impregnated flexible steel cable (3/4 to 7/8" diameter) removed from overhead industrial cranes are used as mooring lines. Standard galvanized cable clamps and U-type shackles are used to fasten the cable to the pipes and the anchors.

All anchors are concrete. The lead anchors weigh 3500 lbs. and contain substantial steel reinforcement. The end mooring lines on the front contain double anchors as well as alternate mooring lines between the end lines on the front. These second anchors and all rear anchors weigh 2200 lbs.

Fabrication of Floating Breakwater Sections

Construction began with the preparation of the pipes for tire cladding. A cylindrical mold of approximately 15-3/8 inch diameter and 2.5 ft. length was fabricated to mold the foam slugs used for filling the steel tubes. End caps with ½ inch pipe plugs on center were welded in place at each end of the tubes. The tubes were pressurized, tested for leaks and then sealed by tightening the plug in the end cap.

A travelling boat cradle crane was used to lift the tubes for threading the truck tires onto the pipe surface. In order to lift the pipe, two wide rubber-covered lift belts were removed from the crane and replaced with steel cables having eyelets at each end. A pipe was lifted by cradling it on the two cables. By propping one end of the pipe onto a fixed block and by moving the cables back and forth one at a time, the tires could be threaded onto the tube past the cables to at least the pipe midpoint (see Figure 5). The procedure was repeated for the other end. Tire retaining lugs were welded to each end of the tube upon completion of the tire cladding. The last operation involved belting the safety protection end tires into place to cover the exposed lugs (see Figure 6).

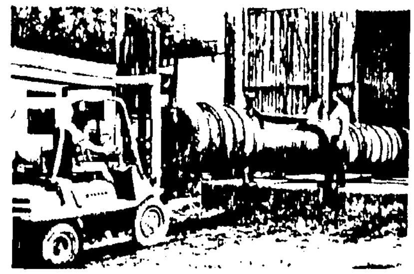

Figure 5. Threading truck tires onto steel pipe.

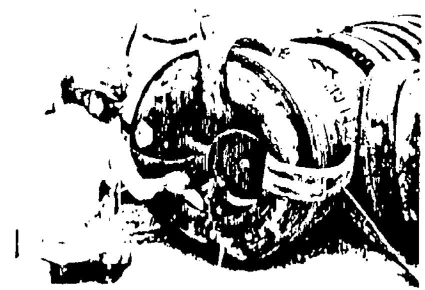

Figure 6. End tires covering retaining lugs.

An early decision was made to foam-fill the steel tubes before sealing. This action assures that the positive buoyancy of the tubes will be maintained in the event of leakage.

Truck tires in the "as received" condition require considerable attention. They usually contain debris and/or torn cords, and/or mutilated tubes and almost always water. The tires were pumped dry, cleaned and hole-punched with three holes in the tread or near the edge of the tread at approximately 120 degree spacing around the periphery. The tires were then branded using a heated steel identification marker in accordance with U.S. Army Corps of Engineers specifications. Tire preparation ended with the addition of a 2 to 3 lb. polyurethane foam slug. The tires were placed in a standing position and sufficient two-part foam mix poured in to fill the tire to the bead edge. In the larger tires, this could be as much as 3 pounds of foam. Care was taken to assure that the more dense, steel belted tires received sufficient foam to assure a good buoyancy. The car tires require approximately 1 lb. to 1.2 lb. of foam to achieve the desired buoyancy. All tires used in the breakwater were foamed in this manner including those used to cover the pipes.

A section of breakwater, for installation purposes, consisted of a tire clad pipe to which was attached a tire matrix. It was found that this assembly could be easily attached in water to another similar one. If the section was to be an interior one, the short length coupling belts were also attached to the side opposite that to which the matrix was connected. This minimized the inwater belt threading type work required to join two sections.

A breakwater section was assembled with the foam in all tires positioned on top just as would occur after launching. The last step in the assembly was to attach the mooring lines to the pipes.

Launching, Towing and Installation

A breakwater section containing a tire cladded tube, tire matrix, mooring lines and threaded coupling belts (if required) was lifted as a unit with the travelling boat cradle crane using the cable straps (see Figure 7). The cable straps were threaded between tires at approximately the 1/3 and 2/3 length points on the tube, connected, and lifted. The approximate weight of the assembled unit was 9.25 tons (assuming an all truck tire section). In some instances the depth of the section was sufficient that some tires were dragged along the ground as it was being moved. For the PGYM-2 sections, it was necessary to pick up the outer 18 tire modules, fold them back, and tie them off on top of the others in order to shorten the depth for lifting and launching.

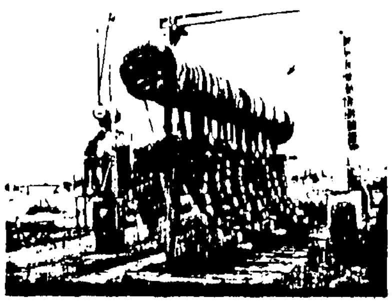

Figure 7. PT-1 section being moved to launching well.

Launching occurred just as with a boat. The crane was driven over the launching well and the breakwater section was lowered into the water. Due to the foam being positioned in the tops of the tires, the tire matrix always assumed the position intended. The mooring lines were thrown onto the matrix and tied in position for towing. At this point one or two persons could walk on the tire cladded tube in order to assist the operation.

The breakwater section was edged slowly out of the launching well with ropes or a pole and immediately two 16 ft. boats, with outboard motor drives, were positioned at the midpoints along each side. The bow and stern of each boat were lashed to the breakwater section. From this point, it was just a matter of steering (see Figure 8) the unit to the site. Steering was effected by increasing the speed of one motor relative to the other.

As the section was maneuvered into position, the motors were stopped until the front mooring line was attached (see Figure 9). The boat next to the other fixed sections was then removed and the remaining boat was shifted into reverse until the section swung into position and could be attached at the front and rear points. On a clam day it required about 1 hour to tow a section approximately 3/4 mile in Presque Isle Bay and perform the described attachment.

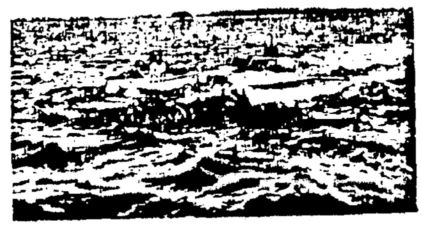

Figure 8. Small boats towing breakwater section to test site.

Figure 9. Worker on breakwater assisting in attaching mooring lines.

It was necessary to work in the water to complete connection of the section. This was best accomplished by two people, one sitting on the tire-cladded tube handling the tools and hardware with the other in the water fastening the binding belts.

Field Test-Site Configuration

The 120 ft. by 40 ft. floating breakwater was installed approximately 360 ft. off the south shore of Presque Isle Bay. The test site is located on municipal property (City of Erie, PA) near the east-west bay midpoint. The fetch from the northwest is 2.5 miles and 1.5 miles from the north and northeast. Water depth is 9 ft. A concrete pier bounds the area on the east side and a stone rubble groin and boat launching ramp are located southeast of the breakwater. Site selection and actual positioning of the floating breakwater within the designated area was the result of a compromise between engineering considerations and the need to afford additional wave protection to the boaters using the public launching ramp. Reflections from the neighboring structures make it necessary to limit data collection to certain wave environments.

In order to obtain accurate wave transmission data, the direction of wave advance must be known. For this purpose, a microprocessor-based, offshore instrument (see Figure 10) capable of measuring significant wave height, significant wave period and wave direction, all in real time, has been developed. The instrument utilizes a triad of equally spaced wire wavestaff sensors to resolve the direction of wave advance. Both the sensor triad and its associated electronic signal processing and data transmission package are housed in a specially designed open-truss, space-frame type tower noted in Figure 1 as the wave tower. Wireless transmission (FM mode) is used to send data to a shore-based microcomputer for final massaging and display.

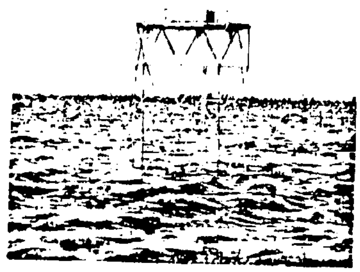

Figure 10. Offshore marine instrumentation platform.

Aft of the breakwater, a single wire wavestaff sensor mounted on a tripod is used to obtain significant wave height measurements. In order to minimize the effects of wave reflections, this instrument is positioned directly behind and quite close to the breakwater. It is moved along the lee edge to obtain transmission data on the three breakwater section designs. Output of this sensor is in analog form and is brought to shore via underwater cable for strip cart recording and analysis.

The positions of all anchors for the structure are know. A surveyor's transit was used on the pier for anchor position determination. Position monitoring of the anchors has been conducted at intervals since installation in July 1982.

Inclement Weather Observations

The first real test of the breakwater and instrumentation came in late November when, following a prolonged period of relative calm weather, a strong cold front moved into the area causing a surge in the bay mean water level and sharply changing weather and wave patterns. The storm was monitored throughout a 17 hour period during which the instrumentation and the floating breakwater performed admirably.

The instrumentation was removed from the water during the first week of December 1982. In January, the bay became ice covered but it was not until the middle of February that the ice coating was sufficiently thick to permit walking on the surface. A close-up inspection of the surface around the breakwater indicated it was completely frozen. Additionally, some lifting of the tire clad tubes along the leading edge occurred. This was estimated to be approximately 8-10 inches. The lifting appeared to be due to fairly large chunks of wind-driven ice being wedged under the leading edge of the breakwater. It is assumed that this phenomenon must have occurred earlier in the winter before the ice pack became rigid. Ice dunes approximately 3 feet high also formed along the front edge of the breakwater. These dunes were entirely limited to the forward surface of the breakwater.

Thawing occurred quickly around the breakwater with the onset of warmer weather. At the first signs of this trend, a day-to-day inspection was instituted. Due to solar heating of the tires, the ice dunes disappeared and ice melted in and around the breakwater well before breakup of the general ice cover occurred (see Figure 11). The movement of the ice cover occurred suddenly and was not observed.

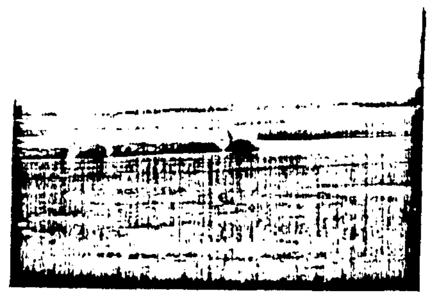

Figure 11. Early ice melting in and around FTB.

Algae growth on the tires was rampant during the late summer months. The tires became so warm during late summer that it was necessary for everyone working on the breakwater to have feet protection. The additional warming of the water by the tires no doubt helped create ideal algae growing conditions. The algae was approximately 6 to 8 inches long when growth subsided in the fall. It turned brown during the winter months and was a brilliant green again by the middle of April. Algae now completely spans the open areas between the tires.

To date, no apparent movement of the anchors and no damage to the breakwater have been observed.

Conclusions

A pipe-tire floating breakwater embodying three different tire matrix designs is performing well in Presque Isle Bay, Erie, PA. An all truck tire section with the matrix tires arranged in a Goodyear modular form appears to be a stiffer configuration and hence a more effective wave attenuator.

Procedures have been established for building pipe-tire floating breakwater subassemblies which can easily be launched with standard marina equipment and towed into position using two small boats with outboard motor drives. On-site joining of pipe-tire floating breakwater sections presents no problems.

The breakwater has survived freezing and thawing conditions during the winter months; however, some lifting of the front edge of the device by wind-driven ice and the formation of ice dunes on the leading edge occurred. To data no damage to the structure and no anchor movement have been observed.

The specially designed instruments for obtaining wave transmission data on the structure appears to be functioning as intended.

Acknowledgements

The author is indebted to Dr. Armand F. Lewis, Behrend College, Penn State University for the extensive technical assistance provided, and to Samuel Hooks, Jeffrey Lewis and John Neumann for their help with the overall project.

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APPENDIX 2

Description of Hydrolab Water Quality Analyzing Instrument.

A Hydrolab Model 6D Surveyor in situ water analysis instrument was used to conduct the study. The battery powered Hydrolab unit is a portable, all-weather field instrument designed for both boat and shore operations under difficult conditions. The unit is capable of measuring dissolved oxygen (D.O.), conductivity, pH, ion concentrations (ORP) and temperature parameters. Temperature-corrected sub-surface data, including depth at which measurements are being made, are available continuously at the surface for observation as functions of depth and/or time.

The basic instrument consists of three major components: the surface (control unit), the sonde (submersible sensor housing) and a connecting instrument cable. After initial calibration, the sonde is submerged to a desired measuring depth. As the sensors respond to ambient water conditions, their output signals are relayed by the instrument cable to the surface unit where the respective signals are amplified, automatically compensated for water temperature, and properly scaled. The resulting finished data signals are then read out directly using the surface unit meter. After calibration, no further manipulation of the surface unit controls is required except for the meter switch and an occasional change of range. Values of D.O., pH conductivity, temperature, ion activity, and depth are simply read out and recorded.

Selected specifications for the instrument follows:

Manufacturer: Hydrolab
P.O. Box 9406
Austin, Texas 78766

Dissolved Oxygen Measurements:

Ranges:	0-10 and 0-20 ppm
Sensor:	Temperature compensated passive polarographic cell
Temperature Compensation Accuracy:	±1.5% of reading, 0°C to 45°C water temperature
Calibration Standards:	Atmospheric oxygen or Winkler-standardized oxygen solutions
Accuracy Overall:	±2% of reading

Conductivity Measurements:

Ranges:	0-100, 0-1000, 0-10,000 micromho/cm
Sensor:	Temperature compensated four electrode AC cell, pure nickel electrodes
Temperature Compensation Accuracy:	±1.5% of reading for salinities up to 34 ppt, temperature between 0°C and 45°C
Calibration Standards:	Internal instrument standard or standard KCl solution
Accuracy, Overall:	±2.5% of reading for internal calibration or ±1.5% of reading for standard solution calibration - salinities to 34 ppt, temperatures between 0°C and 45°C
Response Time:	2 secs. to step change in conductivity, 10 secs. to step change in temperature

pH Measurements:

Range:	2 to 12 pH
Sensor:	pH electrode, reference electrode pair
Temperature Compensation:	Standard slope correction plus offset suppression, 0°C to 45°C
Calibration Standard:	Standard buffer solutions
Accuracy, Overall:	±0.05 pH
Response Time:	10 secs. for step change in pH, 20 secs. for step change in temperature.

Specific ORP Measurements:

Range:	0 to 1000 millivolts linear scale for ORP
Sensor:	platinum electrode, reference electrode pair
Temperature Compensation:	Standard slope correction plus offset suppression, 0°C to 45°C.
Calibration Standards:	Standard ion solution
Accuracy, Overall:	±5 millivolts for ORP
Response Times:	Approx. 15 secs. for step change in ion concentration, 30 secs. for step change in temperature

Temperature Measurements:

Range:	-5° to 45°C
Sensor:	Thermistor probe
Calibration Standard:	Internal
Accuracy, Overall:	±0.2°C for temperatures between -5°C and +25°C, ±0.4°C for temperatures between 25°C and 45°C.
Response Time:	10 secs. for step change in temperature

Depth Measurements:

Range:	0-20 meters
Sensor:	Temperature compensated pressure transducer
Accuracy, Overall:	±1.5% of range

Appendix III

Scientific Names of Fish Observed in the Study.

Check List of the Fishes of Presque Isle Bay Compared with Fishes Reported as Occurring in Lake Erie. (From Aquatic Ecology Associates, 1973, p. 273)

(X = Fishes Collected from Presque Isle Bay)

SCIENTIFIC NAME	COMMON NAME	
ACIPENSERIDAE		
Acipenser fulvescens	Lake sturgeon	X
LEPISOSTEIDAE		
Lepisosteus oculatus	Spotted gar	X
L. osseus	Longnose gar	X
AMIIDAE		
Amia calva	Bowfin	X
CLUPEIDAE		
Alosa pseudoharengus	Alewife	X
Dorosoma cepedianum	Gizzard shad	X
HIODONTIDAE		
Hiodon tergisus	Mooneye	
SALMONIDAE		
Coregonus artedii	Lake Erie cisco	
C. clupeaformis	Lake whitefish	
Salvelinus namaycush	Lake trout	
OSMERIDAE		
Osmerus mordax	Rainbow smelt	X
ESOCIDAE		
Esox americanus vermiculatus	Grass pickerel	X
E. lucius	Northern pike	X
E. masquinongy	Muskellunge	X
CYPRINIDAE		
Carassius auratus	Goldfish	X
Cyprinus carpio	Carp	X
Hybopsis storeriana	Silver chub	
Nocomis biguttatus	Hornyhead chub	X
Notemigonus crysoleucas	Golden shiner	X
Notropis atherinoides	Emerald shiner	X
N. cornutus	Common shiner	X
N. emiliae	Pugnose minnow	
N. heterodon	Blackchin shiner	
N. heterolepis	Blacknose shiner	
N. hudsonius	Spottail shiner	X
N. rubellus	Rosyface shiner	X

Appendix III (cont.)

SCIENTIFIC NAME	COMMON NAME	
CYPRINIDAE (Continued)		
Notropis spilopterus	Spotfin shiner	
N. stramineus	Sand shiner	
N. volucellus	Mimic shiner	X
Pimephales notatus	Bluntnose minnow	X
CATOSTOMIDAE		
Carpiodes cyprinus	Quillback	X
Catostomus catostomus	Longnose sucker	
C. commersoni	White sucker	X
Ictiobus cyprinellus	Bigmouth buffalo	
Moxostoma sp.	Redhorse	X
ICTALURIDAE		
Ictalurus melas	Black bullhead	X
I. natalis	Yellow bullhead	X
I. nebulosus	Brown bullhead	X
I. punctatus	Channel catfish	X
Noturus flavus	Stonecat	
N. gyrinus	Tadpole madtom	
N. miurus	Brindled madtom	
PERCOPSIDAE		
Percopsis omiscomaycus	Trout-perch	X
GADIDAE		
Lota lota	Burbot	
CYPRINODONTIDAE		
Fundulus diaphanus	Banded killifish	X
ATHERINIDAE		
Labidesthes sicculus	Brook silversides	X
PERCICHTHYIDAE		
Morone chrysops	White bass	X
CENTRARCHIDAE		
Ambloplites rupestris	Rock bass	X
Lepomis gibbosus	Pumpkinseed	X
L. gulosus	Warmouth	X
L. macrochirus	Bluegill	X
Micropterus dolomieui	Smallmouth bass	X
M. salmoides	Largemouth bass	X
Pomoxis annularis	White Crappie	X
P. nigromaculatus	Black Crappie	X
PERCIDAE		
Etheostoma exile	Iowa darter	
E. nigrum	Johnny darter	X
Perca flavescens	Yellow Perch	X
Percina caprodes	Logperch	X
P. copelandi	Channel darter	
Stizostedion canadense	Sauger	
S. vitreum	Walleye	X
SCIAENIDAE		
Aplodinotus grunniens	Freshwater drum	X